

PORTS OF THE FUTURE PARTNERSHIP

A QUAD Initiative

REPORT



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The Ports of the Future Partnership: A Quad Initiative

Contents

Introduction	5
1. Ports as Key Development Anchors in the Indo-Pacific	7
2. Infrastructure and Investment: Quad Pathways in the Indo-Pacific	12
3. Digital Infrastructure and Next-Gen Technology	18
4. Shipping and Shipbuilding	24
5. Modernizing Port Logistics and Operations	30

Introduction

The Ports of the Future Partnership: A Quad Initiative Conference was held on 29–30 October 2025 at the Bombay Exhibition Centre in Mumbai as part of India Maritime Week. The Conference marked the inaugural engagement bringing together India, Australia, Japan, and the United States to shape the Indo-Pacific's port infrastructure and connectivity agenda.

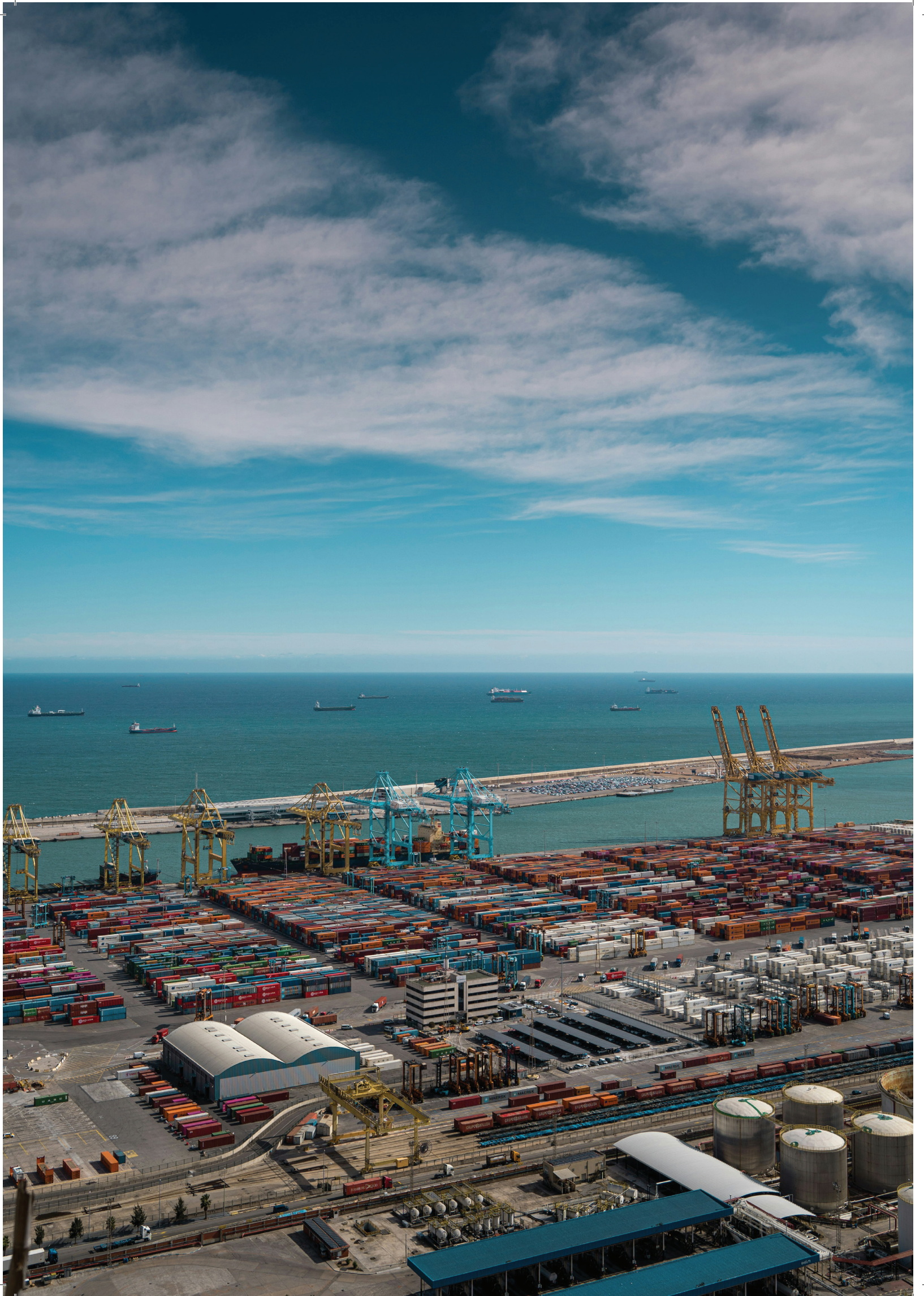
Organized by the Ministry of External Affairs and the Ministry of Ports, Shipping and Waterways, with the partnership of Ananta Centre, the conference drew over 120 senior delegates, including government officials, port authorities, maritime security experts, logistics specialists, shipping industry representatives, and development finance institution leaders. The initiative under the aegis of the Quad included the participation of several Pacific island nations like Kiribati, Tuvalu, Vietnam, Tanzania, Sri Lanka, Palau, and Fiji.

The initiative was derived from the joint statement of the Wilmington Declaration during the Quad Leaders' Meeting in September 2024 and was reiterated during the Quad Foreign Ministers' meeting in July 2025.

The conference emphasized that port modernization needs more than isolated bilateral partnerships or individual national investments. Rather, it demands coordinated action leveraging the Quad's combined economic heft, diverse expertise, and complementary strengths enabling the four nations to offer developing partners genuine alternatives grounded in transparency, rule of law, and demand-driven development.

This report documents the inaugural conference through five substantive sections reflecting the themes discussed:

1. Ports as Key Development Anchors in the Indo-Pacific
2. Infrastructure and Investment–Quad's Pathways in the Indo-Pacific
3. Digital Infrastructure and Next-Gen Technology
4. Shipping and Shipbuilding
5. Modernizing Port Logistics and Operations



1. Ports as Key Development Anchors in the Indo-Pacific

Key Takeaways – Focused on Specific Solutions and Ideas

1. **Integrated Port Development Models:** Develop ports as multifunctional hubs combining logistics, manufacturing, offshore wind, and green fuel infrastructure, thereby moving from cargo handling to full industrial ecosystems.
2. **Quad-Led Port Modernization Initiatives:** Establish a Quad Port Modernization Fund to jointly upgrade existing Indo-Pacific ports, focusing on digitalization, green retrofits, and security resilience instead of only new builds.
3. **Innovative Financing Mechanisms:** Expand blended finance combining concessional loans, equity investment, and PPP models to crowd in private capital while ensuring affordability for host nations.
4. **Transparent Contracting Standards:** Create a Quad Transparency Code for port projects to standardize procurement, prevent dual-use exploitation, and ensure open data sharing on ownership and financing.
5. **Cyber and Climate Resilience Design:** Mandate “resilience-by-design” standards by integrating cybersecurity layers, disaster redundancy, and renewable backup systems into port architecture and IT systems.
6. **Smart Port Technology Integration:** Invest in AI-enabled logistics, digital twins, and blockchain-based cargo tracking to enhance real-time visibility and predictive supply chain management.
7. **Alternative Fuel Readiness:** Build flexible bunkering infrastructure to accommodate multiple next-generation fuels (ammonia, methanol, hydrogen), ensuring long-term adaptability to global energy transitions.
8. **Green Port Certification Framework:** Introduce an Indo-Pacific Green Port Standard that benchmarks ports on renewable energy use, emissions reduction, and circular economy adoption.
9. **Digital Trade Corridors:** Scale initiatives like the India–Middle East–Europe Corridor (IMEC) to link ports through shared customs, e-payments, and logistics data platforms resulting in lowering transaction costs and emissions simultaneously.
10. **Human Capital Development:** Expand Quad Infrastructure Fellowships and establish Maritime Skill Academies at major regional ports to train engineers, digital managers, and sustainability experts.
11. **Women’s Leadership in Port Management:** Institutionalize gender parity targets in port authorities and logistics companies, modeled on Tonga’s and South Asia’s inclusive capacity-building programs.
12. **Interoperable Digital Standards:** Develop Quad-endorsed interoperability protocols for data exchange across port systems to ensure trust, efficiency, and cyber-secure information sharing.
13. **Performance and Benchmarking Tools:** Scale use of the Container Port Performance Index and create Quad Port Performance Dashboards to track modernization, sustainability, and efficiency outcomes in real time.

Ports have evolved far beyond their historical role as commercial gateways to become strategic anchors of industrial development across the Indo-Pacific. The World Bank’s Container Port Performance Index tracks over 350 ports worldwide, underscoring how modern ports now function as integrated hubs facilitating not only trade but also regional growth, resilience, and strategic positioning in an interconnected Indo-Pacific.

Eighty percent of global trade by volume and over 70 percent by value moves by sea, with roughly 60 percent of maritime trade passing through Asia. Indo-Pacific ports therefore, serve, as indispensable arteries of the global economy, making infrastructure investment decisions in the region consequential for worldwide trade flows.

For major trading nations, ports generate immense economic value. In the United States alone, they contribute nearly \$3 trillion to the economy and support one in every eight jobs. Across the Indo-Pacific, well-developed ports act as catalysts for industrial growth, employment, regional integration, and broader economic advancement. Conversely, disruptions—whether from natural disasters, cyberattacks, or terrorism—produce cascading global impacts, underscoring both the interconnect-



edness of supply chains and the critical importance of port resilience.

Today's ports encompass far more than cargo handling. Offshore wind farms, sustainable fuel infrastructure, inland waterways, and industrial corridors are collectively transforming them into multifunctional economic and strategic nodes. This evolution requires port investment, governance, and policy frameworks that align diverse stakeholder interests with emerging technologies.

Ports embody two inseparable dimensions: development and strategy. The development dimension covers industrial growth, employment, tourism, and regional integration, while the strategic dimension involves maritime awareness, supply chain resilience, security, and geopolitical leverage. Ports that neglect either dimension risk falling short of the needs of modern Indo-Pacific economies.

The Quad Framework: Shared Values and Differentiated Strength

The Quad unites four maritime democracies that share fundamental values while offering complementary strengths. Together, these four countries combine almost a quarter of the world's population and over one-third of global GDP. This combined economic heft, coupled with a shared commitment to free, open, peaceful, and prosperous Indo-Pacific principles, positions the Quad uniquely to influence regional port development trajectories.

The Free and Open Indo-Pacific (FOIP) vision provides the conceptual foundation for Quad cooperation. Japan's renewed emphasis on FOIP as a diplomatic pillar, centering on enhanced connectivity, regional capacity building,

and a rules-based international order, articulates the normative framework guiding this engagement. These principles, extending beyond maritime concerns, rest on four pillars: rule of law, rules-based order, connectivity, and capacity building. Port development offers a practical avenue to translate these guiding principles into concrete regional transformation.

India and Australia, as Indian Ocean nations, contribute deep regional understanding. India's maritime development vision and Australia's focus on high-quality, transparent, and climate-resilient infrastructure demonstrate how shared values are operationalized in practice. The United States complements these efforts through technological innovation, financing capacity, and security frameworks grounded in democratic governance.

Building on these shared commitments, the Quad framework also provides the basis for reimagining how ports are financed, governed, and operated ensuring that economic ambition aligns with transparency, efficiency, and long-term resilience.

Financing and Governance Innovation for Port Development

Modern ports demand financing models that go beyond traditional concessional lending. Given the capital intensity of port infrastructure, innovative mechanisms, particularly public-private partnerships (PPPs), are essential. Effective PPPs integrate investment from governments, development finance institutions, and private operators. Without this convergence, port development risks inefficiency or stagnation.

The Quad partnership framework offers a distinctive approach to infrastructure financing. Rather than

pursuing purely independent or bilateral projects, Quad countries increasingly collaborate on joint initiatives, emphasizing modernization over new construction. Many regions already possess port infrastructure that requires upgradation rather than greenfield expansion. Strategic coordination among Quad partners can identify existing ports where joint cooperation delivers better outcomes for host nations and the Quad alike.

Transparency remains a foundational principle. In some regions, ports nominally designated as commercial hubs have been converted to dual-use facilities, serving intelligence or military purposes. Such developments underscore why Quad partners prioritize transparency, clear contractual frameworks, and adherence to international maritime law. Transparency is not peripheral but central to ensuring that infrastructure serves shared growth, sustainability, and strategic trust rather than narrow geopolitical objectives.

However, even with strong governance and financing frameworks in place, ports remain vulnerable to evolving risks, both physical and digital, that can disrupt global commerce and security.

Port Vulnerabilities and Resilience Imperatives

Ports are critical nodes and points of vulnerability within global supply chains. They are the only places where physical cargo and its digital identity converge, creating exceptional exposure to cyber threats. Criminal actors exploit this through phishing, ransomware, and denial-of-service attacks, halting operations and triggering global disruptions.

Rising trade volumes compound these vulnerabilities. Global trade grows about 3% annually, yet ports cannot expand land area at the same rate. To meet throughput demands, they integrate operational and information technology systems—connections that boost efficiency but heighten cyber risk.

Resilience has, therefore, become a strategic imperative. It requires infrastructure hardened against natural and digital threats, redundancy across port networks, diversified trade routes, and logistics systems designed to absorb shocks. Future-ready ports must embed smart technologies, automated terminals, secure subsea cables, and advanced cyber defenses from the design stage rather than retrofitting them later.

These imperatives are reshaping the very nature of port operations, as new technologies redefine efficiency, security, and competitiveness in the maritime domain.

Emerging Technology and Future Port Operations

Several emerging technologies are redefining port operations.

Alternative fuels: The shift away from heavy fuel oil in shipping (currently just 2% of global refinery output) introduces uncertainty among 20+ potential future fuels. Ports must invest in adaptable bunkering infrastructure to remain flexible as fuel standards evolve.

Mega-ships: Larger vessels lower per-unit transport costs but increase dependence on fewer ports. Infrastructure must evolve continuously, not through infrequent large investments but through steady, calibrated capacity additions.

Autonomous vessels: Driven by workforce shortages, automation is advancing despite regulatory uncertainty. Ports must design new operational protocols and interfaces for crewless ships.

Quantum computing and AI: These pose emerging cybersecurity risks, potentially undermining current encryption systems and demanding a complete rethink of digital trust mechanisms.

Climate change: Rising sea levels threaten port viability itself, making climate adaptation a core design and operational principle rather than a secondary concern.

Digital Integration and Supply Chain Visibility

Modern ports function as digitally integrated ecosystems offering near-real-time supply chain visibility. Leading ports now deliver asset-level updates hourly, enabling predictive logistics and precise delivery forecasting. Achieving this requires standardized data protocols, interoperability among ports and transport modes, and shared information frameworks.

Yet, transparency gaps persist particularly in tracking container contents. Full supply chain visibility demands integration extending beyond individual ports to entire logistics networks. Only such digital interconnection enables predictive analytics, AI-driven optimization, and efficient routing.

The Quad vision for resilient supply chains depends on trust and interoperability. Raw materials from Australia feeding Indian manufacturing, semiconductors from Japan, and technology from the U.S. form a “dream fit” that hinges on transparent data-sharing and unified standards. True system integration requires openness that prioritizes collaboration over proprietary advantage.

As digital systems strengthen efficiency, standardized benchmarking ensures that these advances translate into measurable performance improvements across hubs.

Port Performance and Benchmarking

Standardized benchmarking underpins performance improvement. The Container Port Performance Index tracks global efficiency, with JNPA (Jawaharlal Nehru Port Authority) rising from rank 96 to 23 in one year—the steepest improvement ever recorded—thanks to partnerships with world-class operators. This demonstrates how transparency, comparative benchmarking, and collaboration drive exceptional performance gains.

Efficient ports extend capability beyond marine terminals into hinterlands. JNPA's reach now spans 1,400 km, almost triple of the traditional hinterland ranges, enabled by dedicated freight corridors, multimodal integration, and coordinated logistics networks.

This model of efficiency is increasingly intertwined



with sustainability, as ports worldwide move toward greener, low-carbon operations that align with global climate commitments.

Green Ports and Environmental Integration

Sustainability is now non-negotiable in port design. Leading ports operate on up to 70% renewable energy, with the aim of achieving full decarbonization. Transitioning diesel tugs to electric fleets exemplifies practical progress, with several ports committing to full conversion within four years.

Net-zero operations must be embedded from inception. Wadhavan Port–India’s flagship greenfield project–bans diesel truck operations and integrates renewable power and EV infrastructure from the outset, marking a shift from retrofitted compliance to design-led sustainability.

IMEC exemplifies convergence between digitalization and decarbonization. Linking JNPA and Jebel Ali in Dubai, its digital platform aims to cut transaction costs by 30–50%, streamline customs, and unify payments thereby enhancing efficiency while lowering carbon intensity.

Port Partnerships and Regional Integration

Sister-port arrangements foster knowledge exchange and institutional capacity. Partnerships like JNPA–Osaka and emerging ties with Lithuania’s Klaipėda Port enable best-practice sharing, training, and technology transfer. These relationships extend beyond operations to workforce development and stakeholder networking.

The Quad Infrastructure Fellowships Programme,

offering hundreds of fellowships for mid-career professionals across the Indo-Pacific, further reflects commitment to human capital and inclusive growth. Increasingly, port partnerships emphasize women’s economic empowerment, as seen in Tonga’s port project where women hold 67% of management roles, and training programs for over 100 South Asian women engineers.

Regulatory Frameworks and International Cooperation

While the United Nations Convention on the Law of the Sea (UNCLOS) and related maritime conventions provide legal foundations, evolving challenges require adaptive governance. The Quad’s emphasis on transparency, rule of law, and demand-driven development reflects the need to balance sovereignty with multilateral cooperation.

Port security, maritime domain awareness, supply chain integrity, and environmental stewardship demand multi-stakeholder engagement linking governments, port authorities, customs, private operators, and logistics providers. Shared protocols, interoperable systems, and transparent governance structures are essential to ensure both security and efficiency while deepening regional trust and cooperation.

Ultimately, the future of Indo-Pacific port development will depend on how effectively nations align strategic vision with operational innovation–building ports that are not just gateways of commerce, but engines of sustainable, inclusive, and secure growth.



2. Infrastructure and Investment: Quad Pathways in the Indo-Pacific

Key Takeaways Focused on Specific Solutions and Ideas

1. **Quad Joint Investment Mechanism:** Establish a Quad Infrastructure Partnership Fund to coordinate investments, reduce duplication, and pool capital for Indo-Pacific infrastructure projects aligned with transparency and sustainability standards.
2. **India's "Finance-Plus" Model Scaling:** Expand India's approach that links financing with environmental and social outcomes—such as coral relocation, renewable energy integration, and coastal resilience—into Quad-supported projects.
3. **Single-Window Governance Reform:** Create unified single-window clearance systems across ministries and port authorities to cut delays, simplify approvals, and ensure faster, more accountable project delivery.
4. **Performance-Based Concession Frameworks:** Introduce outcome-linked concession contracts that reward efficiency, sustainability, and digital innovation, replacing rigid, time-bound arrangements.
5. **Quad Digital Trade and Logistics Platform:** Develop an interoperable digital platform connecting customs, ports, and shipping lines with shared APIs, enabling real-time tracking, predictive logistics, and trusted data exchange.
6. **Modular Standardization for Quality Infrastructure:** Adopt modular, adaptive design codes suited to local conditions (tsunamis, tides, seismic zones), ensuring quality, resilience, and faster construction timelines.
7. **Tech-Enabled Construction Standards:** Mandate 3D modelling, digital twins, and real-time monitoring tools for all large-scale port and logistics projects to ensure design integrity and efficient lifecycle management.
8. **Green Engineering Integration:** Incorporate renewable technologies such as wave-energy turbines, solar roofs, and electric equipment into marine structures to create climate-resilient and energy-positive ports.
9. **Flexible Quad Co-Financing Models:** Deploy both parallel and leader-supporter models selectively.
10. **Quad Guarantee Facility for Private Capital:** Create a joint guarantee fund to de-risk private investment, signal multilateral backing, and attract long-term infrastructure investors.
11. **Harmonized Quad Standards:** Develop Quad Infrastructure Quality and Resilience Codes with common ESG benchmarks, climate-proofing standards, and local content mandates; or leverage Pacific Quality Infrastructure (PQI) principles.
12. **Shared Digital Twin Repository:** Establish a Quad digital twin library allowing engineers and operators from any member country to access, update, and manage co-developed port infrastructure efficiently.
13. **Strengthened Quad Infrastructure Coordination Group:** Upgrade existing mechanisms with real-time project dashboards, quarterly pipeline reviews, and transparent data sharing among financing institutions.
14. **Single-Country Leadership for Projects:** Assign lead partners per project (example Japan on engineering, India on operations, U.S. on financing, Australia on environmental standards) to streamline execution.
15. **Quad Maritime Training and Fellowship Expansion:** Scale the Quad Infrastructure Fellowships and create Maritime Skill Academies focused on digital logistics, green port management, and automation systems.
16. **Quarterly Quad Financial Alignment Reviews:** Institutionalize structured review cycles among DFIs [Development Finance Institutions] to align risk appetites, ESG criteria, and financing timelines for smoother multi-partner project delivery.

The Indo-Pacific faces an immense infrastructure gap that extends beyond capital shortages. The Asian Development Bank estimates an annual deficit exceeding \$450 billion, while the Global Infrastructure Hub Report 2024 projects a \$3.3 trillion shortfall by 2040. The central question is whether this reflects a lack of capital or gaps in coordination, commitment, and con-



fidence. The Quad's role is not to ask whether to invest, but how to invest together, anchoring cooperation in transparency, sustainability, and mutual respect rather than transactional calculation.

Development Partnership Model and Policy Framework

India's approach to development partnerships and the Quad's collaboration framework, rests on principles that sharply distinguish it from alternative models. India does not view itself as a traditional donor; the Quad's partnerships emphasize non-interference, sovereignty, transparency, inclusiveness, and mutual benefit. These principles underpin India's foreign policy and Quad-aligned financing efforts.

India's \$30 billion concessional credit portfolio spans 70 countries across the Global South. Crucially, India rejects debt-trap diplomacy. Its partnerships are demand-driven, responding to recipient needs, whether for roads, ports, or power, rather than supply-driven project imposition. This stands in contrast to models that prioritize scale over sustainability, often creating long-term debt risks.

Beyond concessional credit, India promotes a "finance-plus" approach—combining infrastructure investment with sustainability and efficiency gains. For instance, India's project to build the largest man-made beach in Maldives also included the world's second-largest coral relocation, aligning development with environmental stewardship.

Given global debt distress observed in the post-COVID era, innovative project financing models must emerge.

Public-private partnerships represent a critical avenue for alleviating debt burdens, particularly in the Global South. India has taken the lead in exploring new financing mechanisms, recognizing that traditional concessional credit alone cannot address infrastructure deficits at the required scale.

However, the success of such financing and partnership frameworks depends equally on institutional and governance efficiency, which often determines whether well-financed projects translate into tangible, high-quality outcomes.

Operational Barriers and Governance Integration

Port performance is often constrained less by technical capacity than by institutional complexity. The ease of doing business in ports depends on governance clarity as much as on infrastructure quality. Overlaps between authorities, regulators, and operators blur accountability and delay execution.

Three systemic barriers persist:

- Project governance – misaligned institutional rhythms delay implementation.
- Institutional agility – rigid procedures impede timely decision-making.
- Supply chain integration – fragmented coordination limits efficiency.

Ports evolve faster than policies governing them. Success therefore requires agile, outcome-based governance which would include faster clearances, empowered local decision-making, and flexible concession frameworks that adapt to technological and market shifts.

Even with improved logistics through dedicated freight corridors—cutting transit times from 72 to 30 hours—data integration across ports, railways, and customs remains incomplete. Policy incentives such as GST parity, balanced pricing, and digital first- and last-mile integration are vital to unlock full efficiency.

Governance alignment cannot rely on regulatory frameworks alone. Single-window clearances administered across government departments with a unified point of contact rather than requiring operators and private sector participants to navigate multiple agencies represent a practical pathway to reducing bureaucratic burden while maintaining accountability and performance standards.

Strengthening such governance and regulatory coordination naturally connects to the next critical frontier of digital integration where institutional efficiency meets technological innovation.

Digital Integration and Supply Chain Visibility

Digital integration emerged as perhaps the most critical enabler of port efficiency and resilience across the conference discussions. The trajectory of digital advancement in India illustrates both achievement and remaining challenges. Advanced ports now provide feedback on asset locations within single-hour intervals through container tracking systems, enabling importers and exporters to know where goods are located and probable delivery times.

In 2020, Indian Customs launched Turant Customs, making the entire customs process faceless, contactless, and paperless. This innovation remains unavailable in many partner countries as of 2025—a marker of India's digital advancement yet also of the considerable development journey remaining.

Despite progress, digital integration remains rudimentary across much of the Indo-Pacific. Critical challenges persist in achieving meaningful supply chain visibility. Current port operations still struggle to track what lies inside containers and pallets which is a fundamental transparency gap that digital systems must address.

The vision articulated by logistics specialists is ambitious: creating truly resilient supply chains through Quad cooperation. Raw materials from Australia flowing into India for basic manufacturing, high-end semiconductors and chips arriving from Japan, combined with technology and software from the United States. This “dream fit” of resilient supply chains depends entirely on trust between countries and seamless digital information-sharing protocols. Such arrangements would be impossible without transparent partnerships and unified data standards.

Digital infrastructure enables more than operational efficiency. It provides the foundation for predictive planning, forecasting capabilities through AI tools, and cargo routing optimization. Yet, achieving this requires governance alignment across customs proce-

dures, unified payment interfaces seamlessly integrated into digital trade systems, and mutual recognition of inspection procedures. These technical challenges are compounded by institutional and regulatory differences across nations.

As digital and operational reforms advance, attention must equally turn to the quality and coherence of physical infrastructure which is the foundation upon which all these systems ultimately depend.

Quality Infrastructure and Plan Coherence

Quality infrastructure construction represents perhaps the most frequently cited constraint on port development effectiveness. Quality depends substantially on available investment, but also on coherent master planning and phase-wise development that preserves integrity with the original vision. The critical challenge is that most port development in India has experienced insufficient funding during implementation, creating a dynamic where phased development loses interface with master plans as optimization occurs at individual phases

The Vadhavan Port in Maharashtra exemplifies India's commitment through the “landlord model,” where government invests in core infrastructure such as 10 km of breakwater and 1,200 hectares of reclaimed land while private players finance berths and equipment. This reduces private entry costs and allows government to capture early returns. The model's success at Vadhavan is being replicated at Great Nicobar Island.

Standardized quality frameworks cannot be applied uniformly across diverse geographies. Marine infrastructure must reflect local conditions like wave patterns, tides, currents, and seismic risks. Japan's infrastructure accounts for tsunamis; North India faces seismic risk, while South India does not. Modular standardization that incorporate local adaptation of common design codes achieves balance between consistency and context.

Modernization and digitalization of design codes accelerate quality construction. While India's labor abundance keeps on-site construction cost-effective, standardized, tech-enabled approaches deliver superior long-term outcomes. 3D modelling, lifecycle analysis, and real-time monitoring help preserve design integrity and quality.

Emerging technologies further enhance innovation. Vadhavan's 10-km breakwater could integrate turbines to convert wave energy into electricity, transforming a passive barrier into an active renewable asset. Such innovations mark a shift from conventional marine engineering toward sustainable, next-generation infrastructure.

Financing Frameworks and Co-Financing Models

Development finance institutions employ two primary Quad financing models: the *parallel model* and the *lead-er-supporter* model.

In the parallel model, each institutional partner (US, Australia, Japan and India) negotiates separately with

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recipient countries, each contributing grants, loans, or guarantees independently. The Palau submarine cable project located in the Western Pacific Ocean exemplifies this approach. The US provided grants and technical advice, Australia provided loans and grants, while Japan provided loans and guarantees, with each institution negotiating separately.

The leader-supporter model centralizes negotiation through one lead partner, with others providing partial guarantees. The acquisition of Digital Pacific, a Pacific Islands telecom company, followed this model wherein Australia led with the primary loan, while the U.S. and Japan offered guarantees. This simplifies negotiation for borrowers while retaining multilateral support.

Each model has trade-offs. The parallel model offers flexibility but creates complex borrower experiences. The leader-supporter model accelerates deal closure but requires close alignment of mandates, ESG standards, and risk appetites.

Effective multilateral financing depends on recognizing each partner's distinct interests and risk-taking capacity. Rather than enforcing a single model, the Quad must identify project-specific approaches through ongoing coordination among financial institutions. Quarterly working-level discussions help identify pipelines, monitor progress, and align strategies.

Speed and flexibility remain decisive advantages. Command economies can act unilaterally, while democracies require consensus. The leader-supporter model offers speed; the parallel model offers adaptability. Strategic deployment of both allows the Quad to compete effectively.

The global private financing landscape requires clear incentive structures. Private investment mobilization depends on host country commitment to materializing projects, coupled with structures enabling private companies to participate profitably. Infrastructure sectors present the challenge that construction and operation may be profitable in certain configurations but not others. Strategic frameworks must identify profitable components, attracting private capital to those activities, while directing governmental support or development finance toward essential but economically challenging elements.

From a private finance perspective, multilateral agency involvement signals lower project risk, enabling investor participation more readily. Private capital flows toward projects with demonstrated multilateral commitment and risk reduction through shared responsibility across partners.

Harmonization, Standards, and Technical Collaboration

Harmonized standards are among the Quad's most powerful tools for accelerating bankable projects. Recipient countries seek clarity on which frameworks apply and confidence in their long-term stability to build trust and foster long-term partnerships.

Common standards for climate and disaster resilience, with precise definitions and engineering specifications, are essential. The Quad must also align on local engagement targets, such as allocating 30% of project expenditure to local labor and materials thereby strengthening partnerships with recipient governments.

Standardized execution frameworks with defined decision gates, accountability, and performance metrics enable predictable, timely project delivery. Too often, projects are delayed by unclear ownership and inconsistent review processes. Harmonization would strengthen the Quad's reputation for reliability.

Shared digital interoperability platforms allow seamless data exchange among ports, shipping lines, and logistics operators. Real-time visibility and multi-modal coordination—essential for efficiency gains from freight corridors—depend on common digital languages and open APIs.

Technical collaboration models emphasize engineering integration of local factors across Quad countries. When projects are conceptualized, designers typically factor local material availability, workforce characteristics, and local skills to optimize costs. However, Quad-level partnerships require integration of inputs from all parties at the outset. Technical teams representing all four countries can collaboratively determine how engineering can be standardized while preserving local advantages. Electromechanical components and equipment selection based on local availability and operational flexibility remain essential factors integrated into engineering design.

Sharing digital twin models and receiving inputs from all partners during project conceptualization ensures that port operators from any Quad country can operate efficiently in ports developed by others. Sufficient data and common design standards enable operators to execute without hindrances. This represents a paradigm shift from port development serving national interests alone toward regional infrastructure supporting multi-country operator deployment.

Such technical harmonization must be matched by equally robust institutional mechanisms and governance architecture to sustain long-term coordination and trust.

Institutional Mechanisms and Governance Architecture

The Quad has established mechanisms for coordination, including the Quad Infrastructure Coordination Group. Structured working groups translate policy agreements into implementation frameworks.

However, these mechanisms must evolve toward dynamic coordination emphasizing transparency, information-sharing, and early-phase investment. Genuine partnership arises when all members commit resources from project inception, creating shared ownership and accountability. This demands open exchange on project pipelines and candid acknowledgment of convergence and divergence.

The shift from parallel to coordinated financing requires trusted, transparent sharing of project information, tools, and institutional capacities. Single-country leadership of specific initiatives, supported by others through guarantees or complementary financing, may

often yield faster and more efficient outcomes than consensus-based approaches.

Quad's Differentiated Approach: Softer Infrastructure Investment

While hard infrastructure like ports, breakwaters, dredging, and equipment remains central, the Quad also prioritizes soft infrastructure through capacity building and training. The Quad Infrastructure Fellowships Programme reflects this, offering over 1800 fellowships to mid-career professionals across the Indo-Pacific, with future cohorts focused on the maritime sector.

Human capacity underpins sustainable infrastructure. As ports modernize and technologies evolve, workforce capability must keep pace. Training ensures that skilled personnel can operate advanced systems and adapt to continuous technological change resulting in resilience and excellence across the port ecosystems in the Indo-Pacific.



3. Digital Infrastructure and Next-Gen Technology

Key Takeaways Focused on Specific Solutions and Ideas

1. **Quad Digital Infrastructure Stack:** Develop a Quad-level Digital Public Infrastructure (DPI) modeled on India's PM Gati Shakti and Unit-Linked Insurance Plan (ULIP), enabling interoperable APIs across customs, ports, and logistics systems for seamless data flow and trade visibility.
2. **Shared Data Standards First, Business Models Second:** Prioritize creation of common data standards, harmonized APIs, and neutral governance frameworks as foundational "digital quay walls," allowing private sector innovation to flourish atop shared infrastructure.
3. **20/80 Minimal Data Framework:** Identify and codify the 20% of essential data elements that enable 80% of port and trade operations, embedding them into harmonized Open APIs under neutral oversight (IMO, WCO, ICC).
4. **Open APIs Across Quad Ports:** Require standardized, publicly documented Open APIs for all Quad ports, ensuring maximum feasible information-sharing without compromising commercial or national sensitivities.
5. **Neutral Data Translation Infrastructure:** Establish a Quad Interoperability and Translation Layer, a country-neutral, agnostic data infrastructure that ingests, normalizes, and redistributes data across diverse port and logistics systems.
6. **Chief Innovation Officers in Every Major Port:** Mandate the creation of dedicated innovation leadership roles (distinct from IT management) reporting to senior executives, tasked with driving digital transformation and ecosystem partnerships.
7. **Procurement-Linked Innovation Mechanism:** Institutionalize Quad hackathons and pilots linked directly to procurement pipelines, where innovators move from testing to paid implementation through structured follow-up funding.
8. **Digital Readiness in All Port RFPs:** Embed digital-by-design criteria covering interoperability, data exchange, and cybersecurity into every new port development or modernization tender.
9. **Cybersecurity-by-Design Standards:** Implement mandatory cyber risk assessments before deployment of new technologies such as AI, drones, IoT sensors, integrating security from inception rather than retrofitting protections.
10. **Quad Digital Twin Network:** Build an interoperable network of port digital twins, sharing real-time data on asset conditions, operations, and capacity utilization to optimize predictive maintenance and resource management.
11. **Standardization Without Duplication:** Adopt a "one framework, many applications" approach to standards aligning with existing ISO, IAPH [The International Association of Ports and Harbors (IAPH)], and UN-ESCAP (United Nations Economic and Social Commission for Asia and the Pacific) frameworks rather than creating new, redundant ones.
12. **AI-Driven Operational Optimization:** Deploy AI-based predictive analytics for vessel scheduling, yard management, and asset maintenance, improving throughput, safety, and emissions performance across ports.
13. **Collaborative "Cooperate-Compete" Model:** Apply open-source collaboration principles for shared port technologies. Stakeholders should co-develop solutions for non-competitive challenges, competing only on service delivery.
14. **Next-Gen Skills Development:** Launch Quad Maritime Digital Skills Academies to train professionals in cybersecurity, data science, AI systems, and network engineering alongside traditional maritime roles.
15. **Organizational Governance for Innovation:** Require ports to establish Innovation Boards or Committees integrating academia, BCOs, and logistics players to ensure technology decisions align with ecosystem needs.
16. **Sequenced Digital Implementation Framework:** Develop Quad digital rollout blueprints that account for ecosystem maturity which implies progressively onboarding customs, trucking, and rail systems into connected port platforms.
17. **Scope 3 Emissions Tracking:** Make Scope 3



emissions reporting by port agents and logistics partners a baseline contractual requirement across Quad-supported ports, enabling transparent environmental accountability.

18. **Quad Digital Public Goods Platform:** Transition from Digital Public Infrastructure (DPI) to Digital Public Goods (DPG) models where open, interoperable systems are co-owned by governments and industry ensuring scalability and neutrality.
19. **Global Legal and Governance Alignment:** Harmonize Quad initiatives with Model Law on Electronic Transferable Records (MLETR) and G20 digital trade document principles, facilitating cross-border recognition of electronic records and smart contracts.
20. **Quarterly Quad Digital Review Mechanism:** Institutionalize quarterly innovation and cybersecurity reviews among Quad ports to track progress, align standards, and ensure collective resilience in digital infrastructure.

Digital infrastructure forms the invisible pier supporting all maritime activity. It is like a piece of architecture that does not rust or corrode but demands constant maintenance. While physical infrastructure draws attention through its tangible presence, digital systems determine whether ports function efficiently or falter catastrophically. The global smart port market illustrates this shift: projected growth from \$3 billion today to over \$14 billion by 2030 reflects recognition that every piece of data, every handshake between systems, and every AI-driven insight saves time, money, and emissions.

The Evolution of Digital Infrastructure: From Linear to Networked

Port digitalization is not new. Rotterdam began developing digital infrastructure in the decades of the 1970s and 1980s, establishing early principles for distributing data through port ecosystems much like cargo itself. The COVID-19 pandemic, however, exposed the limits of linear supply chains: containers sat in Rotterdam while their documents remained in factories in China revealing that fragmented, document-centric systems can paralyze global logistics.

Modern digital transformation recognizes ports as nodes in global networks, not isolated terminals. True transformation means rethinking data itself, not merely digitizing documents. Many current digitalization efforts still replicate analog habits creating digital documents instead of standardizing the underlying data. Progress depends on defining common data models, harmonized APIs, and governance frameworks that enable secure data exchange.

Digital infrastructure provision must precede business model development. Ports and partners should establish shared data standards such as the digital equivalent of building quay walls and let markets innovate atop that foundation. Starting with individual business models creates silos and erodes trust; starting with shared infrastructure fosters interoperability and market-driven innovation.

Among global examples, India's recent digital initiatives illustrate how national digital stacks can provide scalable, interoperable models for maritime transformation.

India's Digital Public Infrastructure Stack

India has undertaken systematic digitalization of maritime and logistics sectors through integrated platforms that exemplify digital public infrastructure approaches. PM Gati Shakti represents an API-based digital stack mapping all infrastructure across the country on a single platform, creating visibility essential for trade with trusted partners. The platform recently opened to private and public sectors, enabling infrastructure planning for both domestic and international players.

ULIP (Unified Logistics Interface Platform) connects 40 systems across 11 ministries through APIs covering road and railway transport, customs, truck operators, transporters, and vessels discharging at ports. Critically, ULIP is not a system or software; it functions as an API-based digital public infrastructure provided free to 1,300+ private companies collaborating on the platform. Over 200 private use cases have been developed atop ULIP, generating applications that deliver business value. This demonstrates that platform software alone proves useless without applications built by businesses solving specific problems.

NLP Marine (part of the Maritime India Vision) addresses coordination challenges among India's 75 operational cargo-handling ports scattered across 7,000 miles of coastline. Historically, individual ports operated state-of-the-art systems that failed to communicate with each other due to different processes, rules, and combinations of procedures. Through "One Nation, One Process" (ONOP) standardization, processes were harmonized across all 75 ports, establishing standardized frameworks based on NLP Marine as the core digitalization infrastructure.

These initiatives illustrate the distinction between digitization (converting analog data) and digitalization (transforming business processes). With over 2,000 commercial ports globally and 40,000 possible process combinations, solutions must allow legitimate regional variation while maintaining interoperability through common standards.

Data Interoperability and Translation Layers

The real challenge in port digitalization lies not in capturing data, but in accessing it. Many operators still rely on EDI, Excel sheets, and flat files which are fragmented systems that make coherent data modeling nearly impossible. A major tire exporter, for instance, could not obtain cargo data from several Latin American ports, rendering tracking impossible.

Creating comprehensive interoperability across diverse stakeholders such as ocean carriers, ports, rail carriers, trucking companies, BCOs (beneficial cargo owners), customs agencies requires recognizing that each player provides different puzzle pieces, often providing similar data in different formats with different meanings. Even identical shipments may carry multiple ETAs or conflicting terminology. Instead of waiting for universal

standards (a process that took decades for shipping containers), effective solutions use translation layers which are agnostic infrastructures that ingest, normalize, and redistribute data across systems.

Such infrastructure must remain neutral—neither country nor company-controlled—to prevent competitive distortions. Blockchain-based attempts failed largely because stakeholders feared data exposure. Success depends on neutral governance that provides shared scaffolding without privileging any participant.

To sustain such innovation over time, ports also require internal governance models and organizational structures that treat digital transformation as a strategic, not peripheral, function.

Organizational Structure and Innovation Governance

Digital transformation demands dedicated structures, not part-time CIO oversight. A Chief Innovation Officer reporting directly to senior management should lead innovation, distinct from IT maintenance roles. Without executive sponsorship, innovation efforts remain peripheral to operations.

Innovation implementation must follow planned trajectories rather than isolated activities. Hackathons, challenges, and pilots serve valuable purposes but must form components of comprehensive implementation plans. Startups typically seek not small prizes from hackathon victories but viable pathways to product sales. Structuring hackathons as pilots developing toward purchasing and implementation creates genuine value: winners receive recognition, pilot opportunities, and pathways to market. Financial capabilities for post-hackathon implementation must exist before initiatives launch.

Collaboration is essential. Ports cannot innovate in isolation. Input from BCOs, logistics firms, academia, and research institutions ensures relevance and sustainability. Partnerships with universities bring new ideas and research depth critical for emerging technology adoption.

Next-Generation Port Operations: Digital Twins and Automation

Building ports as digital-first, automated infrastructure represents a paradigm shift from retrofitting existing facilities. Vizhinjam Port near Thiruvananthapuram, Kerala is India's first automated terminal and "Gen Z port," was conceived digitally from inception. Initial failures during live testing highlighted the learning curve, but within seven months the port handled one million container moves, doubling theoretical capacity and achieving in months what took Rotterdam seven years.

Automation delivers consistent, predictable performance independent of human variability. It dramatically improves safety, reduces error rates, and enables inclusive employment. Women operators and diverse professionals now thrive in roles once physically demanding. This consistency also enables superior planning and

PORTS OF THE FUTURE PARTNERSHIP

A QUAD INITIATIVE

29-30 OCTOBER 2025



scheduling. Safety improvements prove dramatic: automation nearly eliminates incidents endemic to container handling. Error rates plummet, wrong containers going to wrong destinations, cargo theft, and disputes caused by manual intervention vanish.

Technology redefines infrastructure logic: capacity rises not from expansion but from intelligent management and optimized utilization. The same infrastructure handles more cargo through intelligent management. However, automation demands new competencies such as cyber-aware network engineers, data scientists, and AI specialists who are distinct from traditional port operators.

To ensure these technologies scale sustainably, the maritime sector must standardize processes without fragmenting the standards landscape.

Standardization Without Proliferation

The maritime sector needs standardization without multiplying standards. Every entity proposing “its own” standard only deepens fragmentation. The goal is consensus on which existing standards to use and how to govern them. Collaborative standard-setting ensures that data standards, APIs, and governance frameworks remain interoperable and transparent.

Norway’s Port of Oslo illustrates best practice. Working with the Norwegian Mapping Authority, it created standardized port datasets, digital twins of every quay and asset, and open-source APIs. ISO certification and open publication accelerated adoption

across Europe, avoiding redundant effort and enabling rapid scale-up.

Standardization must also extend to design codes and maritime infrastructure, allowing modular regional adaptations for varying conditions like waves, tides, seismic zones without losing interoperability or quality coherence.

Open APIs and Data Governance

Open APIs represent critical infrastructure for port digitalization. All Quad ports should present Open APIs with maximum information available, facilitating collaboration and information sharing. However, defining what constitutes “maximum” information while preventing competitive disadvantage requires careful governance.

By identifying these minimal data sets multilaterally and embedding them in harmonized APIs governed by neutral bodies (IMO for vessel data, WCO for trade data), ports can achieve interoperability without compromising sovereignty or competitiveness. For instance, ICC digitization of trade documents demonstrates that 20% of data elements populate 80% of global trade documentation. Similarly, 20% of operational data facilitates 80% of port processes. This 20/80 principle ensures efficiency, trust, and global alignment.

AI and machine learning now underpin predictive planning, asset management, and supply chain optimization. As data access expands, AI’s impact compounds exponentially across port operations.

Yet emerging technologies also heighten vulnerabil-

ity. Drones circulating port skies, AI implementations across operations, and sensor networks throughout facilities create vulnerabilities requiring proactive management. Cybersecurity by design which means integrating security considerations from the outset of technology development rather than retrofitting protections later represents critical best practice. Every emerging technology implementation must include cyber risk assessment before deployment.

Embedding these standards and safeguards within structured implementation frameworks is key to achieving consistency and scalability across Quad initiatives.

Implementation Frameworks and Governance Models

Standardized execution frameworks defining decision gates, accountability, and outcome-based metrics make regional projects predictable and scalable. Shared digital platforms linking ports, shipping lines, and logistics players ensure real-time visibility and forecasting capabilities.

The challenge of stakeholder maturity alignment demands recognition that port automation cannot proceed faster than ecosystem readiness. Automated ports inevitably encounter manual processes not from automation inadequacy but from partner ecosystem immaturity. Bringing stakeholders such as customs agencies, trucking companies, and rail operators onto digital platforms alongside ports requires sequenced implementation and patience with varying adoption speeds.

Collaborative development models like Norway's Green Shipping Forum demonstrate the "cooperate when you can, compete when you must" principle. Stakeholders competing in some contexts collaborate on shared challenges, developing open-source solutions funded through governmental support (like Norway's Innovation programme). This approach benefits all participants; those refusing collaboration lose funding eligibility as solutions mature.

Frameworks for Digital Public Goods

DPI and DPG frameworks enable open, interoperable ecosystems serving entire sectors. India's experience with digital identity, payments, and logistics showcases DPI's transformative power. The evolution from DPI (government-provided platforms) to DPG (open, shared systems) ensures scalability and sustainability.

Global frameworks—the G20's principles for digital trade documents and UN-ESCAP's Model Law on Electronic Transferable Records (MLETR)—provide a governance foundation. Bharat Trade Net embodies these principles for trade document digitization, creating a replicable Quad-level model.

Collaboration between established entities—IAPH, FIATA, BIMCO, ICC, IPCSA—is preferable to new, competing initiatives. Data collaboration, distinct from data sharing, enables mutual value creation without loss of

ownership. The IAPH–World Economic Forum's five principles of public–private data collaboration guides this evolution.

Translating these principles into tangible cooperation requires practical, time-bound actions that align innovation with implementation.

Practical Action Points for Quad Implementation

- Quarterly Quad hackathons for innovators to demonstrate technologies with procurement-linked pathways.
- Standardized Open APIs across Quad ports sharing maximum feasible information while respecting national data rules.
- Minimal data set identification via multilateral consensus—20% of data enabling 80% of operations—governed by neutral international bodies.
- Chief Innovation Officers in every major port, distinct from CIO roles, to anchor digital transformation at the leadership level.
- Digital readiness criteria embedded in all port RFPs, ensuring technology integration from inception.
- Cybersecurity-by-design standards mandatory for all new technologies and infrastructure projects.
- Collaborative "cooperate–compete" frameworks for open-source solutions with shared funding eligibility.
- Capacity building for next-gen skills—cybersecurity, data science, AI, and network engineering—alongside traditional maritime expertise.
- Scope 3 emissions reporting by port agents as a contractual baseline, establishing transparent environmental accountability.



4. Shipping and Shipbuilding

Key Takeaways – Focused on Specific Solutions and Ideas

1. **Quad Shipbuilding Collaboration Framework:** Establish a Quad Shipbuilding and Maritime Industrial Partnership leveraging complementarities: Australia (raw materials), India (manufacturing), Japan (technology and quality systems), and the U.S. (financing and innovation).
2. **Four-Pillar National Strategy Implementation:**
 - *Financial Assistance Scheme (FAS):* Maintain tiered support (15–25%) and expand green vessel incentives.
 - *Maritime Development Fund:* Scale up soft loans for working capital and modernization.
 - *Shipbuilding Development Scheme:* Co-finance Greenfield and Brownfield expansions with skill-training integration.
 - *Policy Reforms:* Introduce fast-track customs, tax rationalization, and import duty relief for core components.
3. **Domestic Cargo Reservation Strategy:** Enforce policies ensuring 20–30% of India's cargo is carried on Indian-flagged vessels, stimulating demand for domestically built ships and securing sovereign logistics capability.
4. **Regional Cluster Development:** Accelerate state-led shipbuilding clusters (e.g., Paradip, Chennai, Kandla) through SPV models with shared infrastructure and 30% capital subsidies to attract private and foreign shipbuilders.
5. **Phased Technology Transfer Model:** Implement progressive localization by starting with full knockdown assembly (100% imported components), progress to 50–50 sourcing, and reach 100% domestic manufacturing through successive phases.
6. **Landlord Port Model Expansion:** Replicate Kandla's landlord framework, where ports develop basic infrastructure and lease completed facilities to private shipbuilders, lowering entry risks and enabling faster project execution.
7. **Green Bunkering Infrastructure:** Co-develop methanol, hydrogen, and ammonia bunkering terminals alongside shipyards to ensure fuel ecosystem readiness for new-generation vessels.
8. **Ancillary Industry Promotion:** Incentivize propeller, gearbox, and propulsion system manufacturing within industrial clusters to localize supply chains and reduce dependency on imports.
9. **Quad Maritime R&D Collaboration:** Create a Quad Maritime Innovation Fund to co-fund R&D in alternative fuels, smart vessel systems, and modular ship design.
10. **Employment Quality over Quantity:** Reframe expectations: Automation will reduce manual labor but increase high-skill engineering, design, and digital roles, ensuring quality employment in advanced shipbuilding.
11. **Cargo Aggregation Partnerships:** Secure long-term shipping contracts from global commodity firms (e.g., Cargill, Trafigura) to guarantee vessel utilization and stabilize shipyard production cycles.
12. **Dual-Use Vessel Program:** Develop commercial-naval hybrid ship concepts for logistics and emergency deployment, strengthening maritime security without militarizing commercial fleets.
13. **Steel and Raw Material Integration:** Link shipbuilding growth to steel industry expansion (especially in Odisha) to ensure secure raw material supply and lower input costs for domestic yards.
14. **Streamlined Customs and Import Procedures:** Introduce fast-track customs channels and reduced duties for essential ship components to close India's 15–20% cost gap with East Asian competitors.

Shipping and Shipbuilding forms a critical pillar of national security and economic development. Within the Indo-Pacific, it underpins maritime connectivity, trade facilitation, and strategic autonomy. The maritime sector's exponential growth in India signals broader regional transformation, positioning countries with shipbuilding capacity as central players in evolving global trade patterns and the security architecture.

Building upon this strategic foundation, the next major shift emerges in the form of global decarbonization and market transformation which is an inflection point that redefines opportunity for India and the broader region.

The Strategic Opportunity: Decarbonization and Market Transformation

The International Maritime Organization's net-zero target for 2050 presents unprecedented opportunities for countries entering the shipbuilding sector. Estab-



lished leaders like China, Korea, and Japan are operating at full capacity, transitioning toward greener vessels powered by alternative fuels. This shift opens market space for emerging players like India to position themselves as producers of new-technology, smart, and intelligent vessels operating on methanol, green ammonia, and other decarbonized fuels.

India has positioned itself strategically through comprehensive policy support. The government approved a 69,700 crore package to promote shipbuilding facilitating investment, creating infrastructure, and addressing capital-intensive needs for skilled manpower and financing. Ports such as Kandla offer strategic advantages like land availability, waterfront access, and location on key trade routes between Rotterdam and Singapore making them ideal for integrated ecosystems combining shipbuilding with green-fuel bunkering facilities.

Projections indicate that EXIM trade on deep-sea routes will grow by 45–115% by 2050 from its 2020 levels, necessitating a diverse range of new vessels. This demand directly justifies infrastructure investment and capacity expansion.

Consumer–Producer Dynamics: Building Indian Shipping Services

Developing a competitive shipping sector requires understanding the consumer–producer relationship. Shipowners and operators are the primary consumers of shipbuilding capacity. Without their demand, facilities remain underutilized. Currently, importing shipping services into India remains cheaper than using domestic services, representing a fundamental market distor-

tion. Indian vessels currently carry only approximately 8% of India's cargo, while the nation pays 60–65 billion annually in freight to third countries.

Achieving a national fleet capable of carrying 20–30% of India's cargo and eventually exporting shipping services demands integrated planning. Building shipyards alone is insufficient without stimulating domestic demand. The analogy is apt: during emergencies, one needs a personal car, not just taxis. Similarly, a sovereign shipping capacity ensures national cargo movement when international services are unavailable or uneconomical.

Long-term cargo visibility drives shipbuilding demand. When cargo owners like Cargill commit to multi-year movements and partner with shipowners, vessel demand becomes predictable, allowing shipyards to plan investments confidently. This cycle—connecting cargo interests, financiers, shipowners, and shipbuilders—creates commercially viable ecosystems rather than speculative ventures.

India's Four-Pillar Shipbuilding Strategy

India's shipbuilding strategy integrates four key elements:

First Pillar: The Shipbuilding Financial Assistance Scheme (SFAS) allocates 34.74 crores with differentiated support—15% for small vessels, 25% for large ones, and additional incentives for green ships. Vessel scrapping incentives offer 40% of scrap value as credit toward new construction, supporting circular value chains and domestic recycling industries. Foreign shipowners are eligible, expanding the market base. At least 40% of project costs must involve domestic content, ensuring industrial participation and skill development.

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A QUAD Initiative

29-30 OCTOBER 2025, MUMBAI



Second Pillar: The Maritime Development Fund provides soft loans to meet broader industry financing needs.

Third Pillar: The Shipbuilding Development Scheme supports both Greenfield and Brownfield expansion. Alongside government financing that is critical, skill development receives simultaneous investment: the Indian Training and Development Centre (ITDC) in Vizag provides personnel training for shipyard workers. The Indian Maritime University develops curricula for shipyard employment training. This recognition that skilled manpower forms the foundation of sustainable competitive capacity represents essential long-term infrastructure investment.

Fourth Pillar: Policy Reforms systematically address backward-pulling policies constraining sectoral development. These reforms proceed on wartime footing, with continuous refinement.

Together, these four pillars aim to position India among the world's top 10 shipbuilding nations by 2030, and within the top five by 2047 (Amrit Kaal).

Demand Aggregation and Vessel Type Specification

Rather than assuming generic capacity-building, India has conducted systematic demand aggregation across government, PSUs, and private sector stakeholders. This assessment identified approximately 230 vessel types required within the next 10 years: tankers, bulk carriers, specialized vessels, dredgers, and container ships. This demand represents genuine market opportunity requiring capacity across multiple shipyards.

Current Indian shipbuilding capacity consisting of five PSUs and a handful of private yards, cannot satisfy this identified demand.

Market demand specification enables shipyard targeting. Initial focus on particular vessel types such as container ships, tankers, and bulk carriers allows specialization, learning curve benefits, and competitive advantage development. Attempting simultaneous production of diverse vessel classes delays competitiveness across all categories. This principle proves critical: sequencing matters. Building expertise and economies of scale in particular vessel segments precedes diversification. India lacks the capacity to quickly replicate Chinese, South Korean, or Japanese industrial ecosystems developed over decades; a focused approach will enable accelerated competitive positioning.

This strategic focus will also drive regional competition and cluster-based growth among maritime states, spurring innovation and investment.

Regional Clustering and State Competition

Multiple maritime states such as Odisha, Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra actively compete for shipbuilding cluster development. This competitive dynamic drives beneficial outcomes: each state government seeks to offer superior incentives, accelerating comparative advantage development and attracting investor interest. Odisha, hosting Paradip Port, has pursued particularly ambitious strategies.

Paradip's shipbuilding cluster, a 50-50 SPV between the Odisha government and Paradip Port, covers 2,000

acres (90% government-owned). About 1,000 acres are dedicated to shipbuilding capable of producing 1.6 million GTPA, roughly equivalent to 18 Cape-class vessels, with repair capabilities alongside. The remaining 1,000 acres will be developed for ancillary industries, which will generate a 6.4x increase in employment. The total project cost is estimated at 24,700 crores, including 7,000–8,000 crores for dredging to achieve 12-metre draft depths. Odisha has declared shipbuilding a priority sector, offering 30% capital subsidies, with expressions of interest expected soon.

Technology and Innovation Imperatives

Technology selection represents critical strategic choice. Rather than attempting comprehensive autonomous ship development immediately, India focuses on scaling commercial vessel production with energy-efficient technologies. Wind-assisted propulsion (reducing energy use by up to 30%), methanol and hydrogen fuels, hull optimization, and digital voyage analytics all contribute to emissions and cost reduction.

IT and digital integration enhance voyage optimization, weather routing, slow steaming, and predictive analytics capabilities. These layered technologies combine to create comprehensive ecosystem transformation reducing both operational costs and environmental impact.

However, one critical observation merits attention: technology advancement need not imply massive employment generation. Chinese shipyards increasingly employ automation, robotics, and mechanical implements for hull construction and welding, dramatically reducing visible workforce requirements despite maintaining advanced manufacturing capability. India can learn these lessons, avoiding mythologized employment promises. Alternative employment emerges in software, design, engineering, and specialized technical roles, creating quality employment even if raw headcount appears lower than manual production alternatives.

Autonomous vessel development is already occurring: three to four Indian shipyards have constructed autonomous vessels for European clients, though automation systems were fitted after vessel construction. Norwegian clients operate these vessels under local regulations despite globally incomplete autonomous vessel regulatory frameworks. This capability demonstrates that India possesses shipbuilding sophistication enabling advanced technology integration.

The Landlord Model and PPP Frameworks

Kandla Port's experience underscores the value of phased, risk-balanced development. Initial global tenders failed due to unclear policy support and cost differentials. Imported components—steel, engines, propellers, propulsion systems—attract duties and taxation pushing Indian-built vessels to be 15–20% more expensive than Korean, Japanese, or Chinese alternatives.

Kandla Port restructured its approach using a landlord model: the port invests capital to create foundational infrastructure (yards, facilities, supporting infrastructure), specifies target vessel types through market analysis, and subsequently offers completed facilities to technology partners and shipbuilders. This phased approach addresses private sector hesitation about foundational investment risks. The port absorbs infrastructure development costs while shipbuilders provide operating expertise and technology transfer.

Partnership sequencing is crucial. Technology transfer occurs optimally through phased progressions: initial phases involve 100% knockdown kits (components) supplied by partners and assembled in India; subsequent phases progress to a 50–50 sourcing split; and the final phases advance 70–30 sourcing and ultimately 100% indigenous manufacturing. This graduated transition enables consistent technology transfer and skill development while maintaining economic viability throughout progression.

Ecosystem and Ancillary Development

Shipbuilding sector competitiveness depends fundamentally on integrated ecosystem development across multiple dimensions. The steel industry expansion—Odisha alone produces 30% of India's 100+ million tonnes annual steel production, with expansion to another 100 million tonnes planned by 2030—addresses critical raw material requirements. Reducing imported component dependencies proves essential. Domestic propulsion systems, propellers, gearboxes, and specialized equipment development require deliberate ecosystem cultivation.

Attracting global component manufacturers requires demonstrating sustained demand and simplifying customs procedures for capital equipment. Many projects face delays due to clearance bottlenecks. Diplomatic engagement with Germany, Japan, and Korea complements industrial policy, encouraging component localization through trusted partnerships.

Partnership Models and Strategic Alignment

Cargo aggregation partnerships such as long-term commitments from global traders like Cargill create predictable demand for Indian-built vessels. Dual-use ship concepts, inspired by China's logistics fleets, are under Navy review, offering peacetime commercial utility and emergency transport capacity. Hull design modifications accommodate this versatility without compromising commercial cargo capacity. Such vessels always remain in supply-line roles rather than front-line combat positions but provide significant strategic capacity.

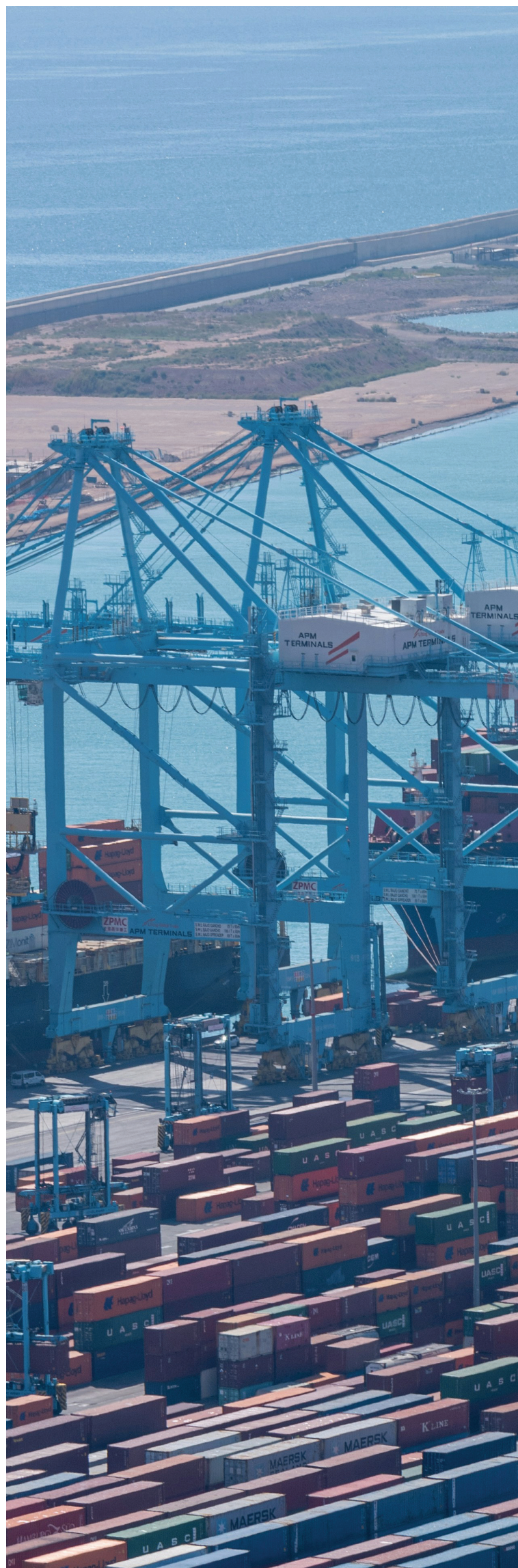
Simultaneous development of green fuel bunkering infrastructure—methanol, hydrogen, ammonia—is essential to support next-generation vessels.

Innovation and R&D Support Mechanisms

India has established frameworks for innovation support. The Maritime Development Fund provides 25+ crores for research activities. Maritime University reviews proposals submitted to DG Shipping, forwarding them to the National Shipbuilding Mission for evaluation and funding. This institutional framework enables systematic R&D support for innovations across the ecosystem.

Internationally, the EU's Horizon 2020 model, linking industry, academia, and government, illustrates best practice. A similar Quad-aligned framework could enable collaborative R&D for next-generation vessel design and green technologies.

Strategic focus, not overextension, drives competitiveness. India should prioritize container ships and bulk carriers—less complex but high-demand categories—before moving into advanced segments such as LNG carriers or research vessels. Specialization builds efficiency and learning-curve advantages, enabling diversification later.





5. Modernizing Port Logistics and Operations

Key Takeaways Focused on Specific Solutions and Ideas

1. **Layered Modernization Model:** Port modernization must combine hard infrastructure, digital infrastructure, sustainability, and cross-border alignment to create seamless, resilient ecosystems rather than isolated facility upgrades.
2. **Regulatory and Policy Reform:** Implement the new Indian Ports Act to ensure uniform governance; strengthen PPP frameworks and fast-track dispute resolution to attract private and global investment.
3. **One Nation, One Port System:** Standardize customs, cargo handling, and documentation through a single interoperable digital model thereby reducing clearance time and aligning with global port standards.
4. **Cross-Border Digital Corridors:** Scale up the Maitri Virtual Trade Corridor (India–UAE) to connect customs and port systems; replicate with Singapore, Rotterdam, and other Quad economies for digital and green trade facilitation.
5. **East–West Load Balancing:** Prioritize investments and incentives for east coast ports (Vizag, Ennore, Paradip) to capture cargo currently routed via third country ports and enhance coastal distribution efficiency.
6. **Enhanced Hinterland Connectivity:** Expand rail-linked inland terminals (120+ locations), integrate Dedicated Freight Corridors, and deploy electric trucking fleets with battery-swapping to close last-mile gaps.
7. **Tariff and Licensing Flexibility:** Allow market-based pricing and migrate legacy concessions to new tariff norms by 2027 to foster competition and improve service standards.
8. **Reviving Coastal and Inland Shipping:** Enable international and domestic operators, e.g., CMA CGM to expand Indian-flag operations; upgrade port infrastructure to handle coastal cargo and integrate inland waterways.
9. **Automation for Mid-Tier Ports:** Deploy modular automation kits such as remote cranes, smart gates, IoT cargo tracking to modernize smaller ports without large-scale capital expenditure.
10. **Multi-Fuel Systems:** Build renewable + battery storage infrastructure and pilot Small Modular Reactors (1–10 MW) for energy reliability. Incorporate multi-fuel (LNG, hydrogen, ammonia, methanol) systems at planning stage.
11. **Industrial–Port Integration:** Establish port-adjacent industrial and logistics parks to cut transit times and costs, coordinated through Gati Shakti and state-level planning for land alignment.
12. **Corridor and System Standardization:** For IMEC and the International North-South Transport Corridor (INSTC), align rail gauges, truck specs, customs codes, and digital trade systems to create interoperable trade routes.
13. **Replicable Global Models:** Adapt proven frameworks from Lao PDR dry ports and Zambia’s inland logistics systems to India’s hinterland for synchronized multimodal connectivity.

Port modernization extends far beyond physical expansion or isolated technology adoption. It represents a dynamic interplay of technology, infrastructure, and policy—creating integrated ecosystems that enable efficient trade, sustainable operations, and strategic advantage in global commerce. The modernization imperative arises from both external disruptions and internal optimization: COVID-19 accelerated paperless trade; geopolitical shifts demanded new trade routes; and Quad leadership identified ports as strategic infrastructure requiring transformation toward green, resilient systems.

The Multi-Layered Modernization Approach

Port modernization unfolds across distinct yet interconnected layers:

Hard Infrastructure: Berths, draft depth, handling equipment, and breakwaters that enable vessel and cargo operations. Capacity expansion must proceed at a steady pace in that frequent, incremental upgrades are more effective than infrequent massive investments that strain deployment efficiency.

Digital Infrastructure: Integrated systems enabling customs processing, data exchange, and supply chain



visibility. Standardization across ports and regulatory integration form the backbone of digital modernization.

Sustainability: Green fuel infrastructure, renewable energy systems, emissions-reduction frameworks, and circular economy practices embedded across port ecosystems.

Cross-Country Collaboration: Trade corridors, system integration with partner nations, and regulatory alignment ensuring seamless cross-border goods movement.

India's Comprehensive Port Modernization Framework

The Indian government functions as an enabler and facilitator, promoting partnerships with international and domestic players rather than exercising monopolistic control. Yet, modernization requires policy and regulatory certainty.

The revamped Indian Ports Act, updated after a century, aligns with global standards and provides a robust framework for infrastructure development that is crucial for attracting private investment.

PPP Dispute Resolution Mechanisms address investor concerns: an adjudicatory board bypasses regular courts for fast-track resolution, while conciliation mechanisms outside court systems ensure speed and predictability. Historical cases once delayed for years now conclude within a couple of years, offering investor confidence.

Standardized Port Processes under the "One Nation, One Port Process" initiative harmonize procedures across Indian ports. A unified digital data model ensures interoperability, enabling cross-port coordination and

optimized cargo routing. Alignment with international conventions ensures seamless interaction with global partners.

The India–Middle East–Europe Corridor (IMEC) exemplifies regional integration. The "Maitri" virtual trade corridor between India and the UAE unifies port, customs, and immigration systems under a single digital framework. Cross-cultural coordination, system mapping, and data security are complex challenges that the initiative overcame and with 90% completion, pilot operations are imminent. If successful, this model could replicate across multiple partner countries.

Similar frameworks with Singapore (digital and green shipping corridors) and Rotterdam (green shipping initiatives) demonstrate scalable proof-of-concept approaches that can be extended across Quad partnerships.

Hinterland Connectivity and Domestic Load Balancing

India's container logistics have evolved dramatically over the last two decades. Once concentrated in northern corridors such as TKD, Dadri, Ludhiana and linked inefficiently to Nhava Sheva, containerization now reaches industrial clusters nationwide. Around 120 rail-connected locations which exceed the Gati Shakti target reflect this transformation from centralized "dry ports" to a distributed container network.

Dedicated Freight Corridors (DFCs) have revolutionized rail logistics. Double-stacked trains, once considered unfeasible, are now standard. The Western DFC's imminent connection to Nhava Sheva will further

improve throughput. Telescopic, multi-point dipping models have shifted rail operations from rigid point-to-point movements to flexible, optimized systems.

However, east-west load balancing remains incomplete. The east coast (Kolkata, Vizag, Haldia, Ennore, Kattupalli, Chennai, Tuticorin) experiences significant underutilization relative to western coast concentration (Mundra, JNPT). Approximately 60–70% of East Coast India cargo transships through Colombo rather than utilizing Indian east coast ports. This inefficiency where cargo moves from Kolkata to Mumbai by rail for export through western ports, results in lost economic opportunity and increased logistics costs.

Domestic hinterland connectivity is being further aided by:

First/Last-Mile Distances: Rail connectivity to industrial locations has reduced first/last-mile distances from historical 300–400 kilometres to 50–80 kilometres in most industrial clusters. E-truck adoption and electric vehicle deployment address remaining distances; JM Baxi has deployed 1,000 electric trucks with battery-swapping capabilities at terminals and ICDs.

Tariff and Licensing Evolution: Historical tariff constraints limiting private operator pricing are transitioning toward market-based frameworks. Since 2021, new terminals operate with pricing freedom; pre-2021 concession-holders are transitioning through tariff migration guidelines. This evolution puts operators on equivalent platforms.

Rail Licensing Transitions: The first round of rail licensing commenced 20 years ago; current discussions suggest 2027 as the end date with potential transition toward open markets without licensing restrictions.

Coastal Shipping Reactivation: Coastal shipping, largely dormant in recent years, is experiencing a revival. International operators including CMA CGM registering four vessels under the Indian flag, and other international companies exploring coastal participation represent significant validation. This modal reactivation requires port infrastructure that can support domestic coastal movements.

Inland Waterways Expansion: Multiple maritime states simultaneously pursue shipping cluster development, creating competitive environments driving superior policy offerings and infrastructure investment.

Private Sector Modernization: Adani Ports Case Study

Adani Ports exemplifies modernization through consistent capacity expansion, technological investment, and operational replication. Beginning with Mundra's transformation from a P&O facility to a high-efficiency hub, Adani has replicated this model across Hazira, Ennore, Kattupalli, and now Vizhinjam. The key differentiators include:

- **Technology and Automation:** Vizhinjam operates as a semi-automated, high-tech terminal. The model's

replication at Colombo West International Terminal demonstrates regional technology transfer at Quad-adjacent regional levels.

- **Transshipment Gateway Development:** Vizhinjam addresses India's historical absence from transshipment markets. India's indigenous EXIM cargo volumes historically rendered transshipment unnecessary; Its emergence and handling one million TEUs creates alternatives to the Colombo-dependent transshipment flows. Colombo's 8+ million TEU capacity is already saturated.
- **Regional Complementarity:** Vizhinjam and Colombo function complementarily rather than competitively as the availability of capacity determines cargo routing. Colombo's capacity saturation means all new growth transships through Vizhinjam and this represents regional development rather than market cannibalization.

Integration Beyond Standalone Port Operations

Modern logistics recognize ports as nodes within end-to-end supply chains, not isolated facilities. Delays at anchorages, gates, or berths ripple through entire trade networks. Integration of IoT, AI, and blockchain reduces idle times, costs, and emissions demonstrating that efficiency and sustainability reinforce each other.

Corridor performance analysis measuring time, cost, reliability, predictability, and emissions reduction validates that ports are only as strong as their weakest inland links. Modernization must address end-to-end supply chain resilience rather than optimizing isolated port operations.

Automation is no longer exclusive to mega-ports. Modular systems—automated gates, remote operations, and retrofittable solutions—allow “automation for all.” This democratization enables smaller Indo-Pacific ports to compete globally despite scale limitations.

Renewable energy with storage remains central, but emerging technologies like Small Modular Reactors (SMRs) in the range of 1–10 MW offer potential for clean, reliable power to terminals, SEZs, and cold chains. Multi-fuel infrastructure for LNG, hydrogen, ammonia, methanol, and shore power must be embedded in initial design, not retrofitted later.

Sustainability-linked loans tie financing costs to emissions outcomes. Port performance indicators, like vessel or truck idle time, serve as emissions proxies. Meeting targets reduces loan rates and missing them triggers penalties, thereby making sustainability financially rewarding.

Australian ports have pioneered this model, documenting emissions reductions across Scopes 1–3 and attracting green capital while driving decarbonization.

Proximity of industries to ports multiplies efficiency returns. Industrial parks, free trade zones, and logistics parks positioned near port facilities reduce transportation distances and modal transitions. Government coor-



dination across industries, ministries, and state governments identifies land parcels; some initiatives are already operational. Strategic positioning of industries within port catchment areas transforms ports from isolated trade nodes into integrated industrial ecosystems.

Challenges and Enablers in Cross-Border Integration

The Maitri corridor highlights key learnings for system integration.

The **challenges** include:

- **People-to-People Understanding:** Bureaucratic and operational team alignment across countries proves more difficult than technological integration.
- **System Interoperability:** Different architectures, data structures, and nomenclature necessitate mapping efforts. Same data elements called by different names in different countries require translation protocols.
- **Data Privacy and Security:** Cross-border data sharing demands trust frameworks, confidentiality protocols, and security documentation ensuring both countries maintain data protection.
- **Political Will:** High-level political commitment provides institutional strength enabling teams to overcome obstacles and cut through bureaucratic delays.

The **enablers** include:

- **Phased Implementation:** Rather than attempting a comprehensive integration, focusing initially on

core entities such as port authorities, customs, immigration, and then expanding progressively, provides a manageable approach.

- **Pilot Testing:** Testing document and data movement validates that the system fully integrates before full operational deployment.
- **International Convention Alignment:** Aligning the system with international frameworks such as those of the WCO, IMO, and UN conventions makes it easier to replicate the model with other trading partners.

Manufacturing Export Surplus and the Quad's Role

India's transition to a manufacturing export surplus is a multi-decade project. Past growth was service-led, yielding a surplus in goods-plus-services but a deficit in goods alone. The New Industrial Missions in semi-conductors, green hydrogen, shipbuilding represent long-gestation strategic shifts.

Quad can accelerate this transformation through:

- **Knowledge Transfer:** Best practices in industrial policy, connectivity, and workforce development.
- **Technology Partnerships:** Joint R&D and co-development in advanced manufacturing.
- **Supply Chain Integration:** Embedding Quad manufacturing hubs in shared regional value chains.
- **Infrastructure Standardization:** Harmonized port and logistics standards for seamless trade.

Similarly, trade corridors like IMEC and INSTC can

benefit landlocked nations by standardizing infrastructure and procedures. Their success depends on:

- **Infrastructure Alignment:** Standardized rail gauges, truck specs, and handling equipment.
- **Regulatory Integration:** Harmonized customs and certification systems.
- **System Connectivity:** Linked port community and digital documentation systems enabling paperless trade.

- **Trust and Collaboration:** Political and institutional alignment across participating states.

Examples such as Lao PDR's dry ports and Zambia's seamless cargo flow models demonstrate that integrated corridors can transform inland connectivity.

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